# METHOD AND APPARATUS FOR MULTI-PATH ELIMINATION IN A WIRELESS COMMUNICATION SYSTEM

## BACKGROUND OF THE INVENTION

### I. Field of the Invention

**[1001]** The current invention relates to communication. More particularly, the present invention relates to multi-path elimination in a wireless communication system.

### II. Description of the Related Art

**[1002]** Communication systems have been developed to allow transmission of an information signal from an origination station to one or more physically distinct destination stations. In transmitting the information signal from the origination station over a communication channel, the information signal is first converted into a form suitable for efficient transmission over the communication channel. As used herein, the communication channel comprises a single path over which a signal is transmitted. Conversion, or modulation, of the information signal involves varying a parameter of a carrier wave in accordance with the information signal in such a way that the spectrum of the resulting modulated carrier is confined within the communication channel bandwidth. At the destination station the original information signal is replicated from the modulated carrier wave received over the communication channel. Such a replication is generally achieved by using an inverse of the modulation process employed by the origination station.

**[1003]** Modulation also facilitates multiple-access, i.e., simultaneous transmission and/or reception of several signals over a common communication channel. Multiple-access communication systems often include a plurality of remote subscriber units requiring intermittent service of relatively short duration rather than continuous access to the common communication channel. Several

multiple-access techniques are known in the art, such as time division multiple-access (TDMA), frequency division multiple-access (FDMA), and amplitude modulation (AM). Another type of multiple-access technique is used in a code division multiple-access (CDMA) spread spectrum system that conforms to the "TIA/EIA/IS-95 Mobile Station-Base Station Compatibility Standard for Dual-Mode Wide-Band Spread Spectrum Cellular System," hereinafter referred to as the IS-95 standard. The use of CDMA techniques in a multiple-access communication system is disclosed in U.S. Patent No. 4,901,307, entitled "SPREAD SPECTRUM MULTIPLE-ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS," and U.S. Patent No. 5,103,459, entitled "SYSTEM AND METHOD FOR GENERATING WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM," both assigned to the assignee of the present invention and incorporated herein by reference.

**[1004]** A multiple-access communication system may carry voice and/or data. An example of a communication system carrying both voice and data is a system in accordance with the IS-95 standard, which specifies transmitting voice and data over the communication channel. A method for transmitting data in code channel frames of fixed size is described in detail in U.S. Patent No. 5,504,773, entitled "METHOD AND APPARATUS FOR THE FORMATTING OF DATA FOR TRANSMISSION", assigned to the assignee of the present invention. In accordance with the IS-95 standard, the data or voice is partitioned into code channel frames that are 20 milliseconds wide with data rates as high as 14.4 kbps. Additional examples of communication systems carrying both voice and data are communication systems conforming to the "3rd Generation Partnership Project" (3GPP), embodied in a set of documents including Document Nos. 3G TS 25.211, 3G TS 25.212, 3G TS 25.213, and 3G TS 25.214 (the W-CDMA standard), or "TR-45.5 Physical Layer Standard for cdma2000 Spread Spectrum Systems" (the IS-2000 standard).

**[1005]** An example of a data only communication system is a high data rate (HDR) communication system, such as the communication system disclosed in co-pending application serial number 08/963,386, entitled "METHOD AND APPARATUS FOR HIGH RATE PACKET DATA

TRANSMISSION," filed 11/3/1997, assigned to the assignee of the present invention. The HDR communication system defines a set of data rates, ranging from 38.4 kbps to 2.4 Mbps, at which an origination station (access point, AP) may send data to a receiving terminal (access terminal, AT).

**[1006]** The information signal to be exchanged among the terminals in a communication system is often organized into a plurality of packets. For the purposes of this description, a packet is a group of bytes, including data (payload) and control elements, arranged into a specific format. The control elements comprise, e.g., a preamble and a quality metric. The quality metric comprises, e.g., cyclical redundancy check (CRC), parity bit(s), and other types of metric known to one skilled in the art. The packets are usually formatted into a message in accordance with a communication channel structure. The message, appropriately modulated, traveling between the origination station and the destination station, is affected by characteristics of the communication channel, e.g., signal-to-noise ratio, fading, time variance, and other such characteristics. Such characteristics affect the modulated signal differently in different communication channels. Consequently, transmission of a modulated signal over a wireless communication channel requires different considerations than transmission of a modulated signal over a wire-like communication channel, e.g., a coaxial cable or an optical cable. In addition to selecting modulation appropriate for a particular communication channel, other methods for protecting the information signal have been devised. Such methods comprise, e.g., encoding, symbol repetition, interleaving, and other methods known to one of ordinary skill in the art. However, these methods increase overhead. Therefore, an engineering compromise between reliability of message delivery and the amount of overhead must be made. Even with the above-discussed protection of information, the conditions of the communication channel can degrade to the point at which the destination station possibly cannot decode (erases) some of the packets comprising the message. In data-only communications systems, the cure is to re-transmit the non-decoded packets using an Automatic Retransmission reQuest (ARQ) made by the destination station to the origination station.

**[1007]** One characteristic, affecting the communication link in wireless communication systems is an intra-cell multi-path interference. The intra-cell multi-path interference is caused by an existence of multiple paths along which a signal, transmitted from an origination station, reaches a destination station. The concept of a multi-path interference is illustrated in **FIG. 1**, where the origination station, e.g., a base station (BS) **102** transmits a signal, which reaches the destination station, e.g., a remote station (RS) **104** along two paths **106, 108**. The presence of multi-path reduces received carrier to interference (C/I) ratio. The received C/I can be determined in accordance with the following equation:

$$\frac{C}{I} = \frac{S_1}{I + S_2} + \frac{S_2}{I + S_1}, \tag{1}$$

where:
C is the signal carrier power received,
I is the interference,
$S_1$ is the component of signal power received along path **106**, and
$S_2$ is the component of signal power received along path **108.**
Elimination of the multi-path components, e.g., path **108**, reduces Equation (1) to the following equation:

$$\frac{C}{I} = \frac{S}{I}, \tag{2}$$

where:
$S = S_1 + S_2$ is the signal power received.

**[1008]** One of ordinary skill in the art recognizes that the C/I ratio given by Equation (2) is greater than the C/I ratio given by Equation (1). Therefore, reduction of the intra-cell interference caused by multi-path components results in an increase of the received C/I. Increased C/I at the RS **104** benefits performance of a wireless communication system by, e.g., increase in capacity, increase in data throughput, and providing other benefits known to one skilled in

the art. Therefore, it is desirable to eliminate the multi-path interference. One approach to eliminate the multi-path interference utilizes equalization and pre-coding techniques.

**[1009]** **FIG. 2** illustrates a method eliminating the multi-path components by equalization at a receiver. A transmitter **202** transmits signal $S_{Transmitted}$ over a communication link **204**. The communication link is characterized by a metric, e.g., an impulse response, a transfer function or other characteristics known to one skilled in the art. For the purposes of illustration, a transfer function A(z) is used. The communication link introduces noise N **206** and the resulting signal and noise is provided to an equalizer **208**. If the equalizer is characterized by a transfer function $\frac{1}{A(z)}$, then a receiver **210** receives signal given by the following equation:

$$S_{Received} = (S_{Transmitted} \cdot A(z) + N) \cdot \frac{1}{A(z)} = S_{Transmitted} + \frac{N}{A(z)}, \tag{3}$$

where:
N is the communication channel noise,
$S_{Transmitted}$ is the signal transmitted, and
$S_{Received}$ is the signal received.

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**[1010]** A disadvantage of this approach is potential amplification of noise for $A(z) << 1$. Pre-coding the signal at a transmitter instead of performing equalization at the receiver may eliminate this disadvantage. Pre-coding at the transmitter is illustrated in **FIG. 3**. A transmitter **302** comprises a data source **304**, which provides data to be transmitted to a pre-coder **306**. The pre-coded data are then transmitted over a communication channel **308**, characterized by a transfer function A(z). The communication channel introduces noise N **310** and the resulting signal and noise are provided to a receiver **312**. If the pre-coder **306** is characterized by a transfer function $\frac{1}{A(z)}$, then the receiver **312** receives a signal given by the following equation:

$$S_{Received} = S_{Transmitted} \cdot \frac{1}{A(z)} \cdot A(z) + N = S_{Transmitted} + N \qquad (4)$$

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**[1011]** Examination of Equation 4 reveals that the noise amplification problem has been eliminated for all values of $A(z)$, however, for $A(z)$ << 1 the power required for correct pre-coding may exceed the transmitter's **302** available power. To eliminate the available power problem, one pre-coding scheme performs a $(1/A(z))\text{mod}(P_{Transmitted})$ transformation on the data prior to transmission. $P_{Transmitted}$ is the maximum power level at which the transmitter can transmit. At the receiver an inverse transformation $\text{mod}(P_{Transmitted})$ is carried out on the received data prior to decoding.

**[1012]** Further details of pre-coding may be found in M. Tomlinson, "New automatic equalizer employing modulo arithmetic," Electronic Letters, Vol. 7, March 1971, pp 138-139, and G. D. Forney and M. V. Eyuboglu, "Combined equalization and coding using pre-coding," IEEE Comm. Magazine, Dec. 1991, pp. 25-34.

[1013] Based on the foregoing, there exists a need in the art for a method and an apparatus eliminating multi-path by applying pre-coding and equalization to multiple-access wireless communication system.

## SUMMARY OF THE INVENTION

**[1014]** In one aspect of the invention, the above-stated needs are addressed by determining a pre-coder parameters; pre-coding first data in accordance with said determined pre-coder parameters; transmitting a pre-coded first data; and transmitting a non pre-coded first reference data. The pre-coder parameters are determined by receiving a reference data; and determining the pre-coder parameters in accordance with said received reference data and the reference data.

**[1015]**In another aspect of the invention, the pre-coder parameters are determined by receiving the non pre-coded first reference data; determining the

pre-coder parameters in accordance with said received non pre-coded first reference data and the first reference data; and transmitting said determined pre-coder parameters.

**[1016]** In another aspect of the invention, the pre-coder parameters are determined by equalizing the received non pre-coded first reference data and provide equalized non pre-coded first reference data; determining the pre-coder parameters by adjusting characteristics of the at least two equalizers in accordance with the received non pre-coded first reference data and the first reference data; and transmitting said determined pre-coder parameters.

**[1017]** In yet another aspect of the invention, the above-stated needs are addressed by receiving a reference data and a pre-coded data; and determining demodulator parameters in accordance with the said received reference data and the reference data; and demodulating the pre-coded data in accordance with said determined demodulator parameters.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[1018]** The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify elements correspondingly throughout and wherein:

**[1019]** **FIG. 1** is a conceptual illustration of multi-path interference;

**[1020]** **FIG. 2** is a conceptual illustration of equalization of multi-path interference at a receiver;

**[1021]** **FIG. 3** is a conceptual illustration of pre-coding at a transmitter and equalization of multi-path interference at a receiver;

[1022] **FIG. 4** illustrates a conceptual diagram of a multiple-access communication system.

**[1023]** **FIG. 5** illustrates a forward link waveform in accordance with one embodiment of the invention;

**[1024]** **FIG. 6** illustrates a forward link channel time-slot in accordance with another embodiment of the invention;

**[1025]** **FIG. 7** is a block diagram of a transmit terminal in accordance with one embodiment of the invention; and

[1026] **FIG. 8** is a block diagram of a receive terminal in accordance with one embodiment of the invention.

[1027] **FIG. 9** illustrates a conceptual diagram of a multiple-access communication system with multiple receive antennae.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

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**[1028]** **FIG.4** illustrates a conceptual diagram of a multiple-access communication system **400** capable of performing the method in accordance with embodiments of the present invention. An AP **402** transmits data to an AT **404** over a forward link **406(1)**, and receives data from the AT **404** over a reverse link **408(1).** Similarly, the AP **402** transmits data to the AT **410** over a forward link **406(2)**, and receives data from the AT **410** over a reverse link **408(2)**. In accordance with the exemplary embodiment of the data communication system of the present invention, forward link data transmission occurs from one AP to one AT. Reverse link data communication occurs from one AT to one or more APs. Although only two ATs and one AP is shown in **FIG. 4**, one of ordinary skills in the art recognizes that this is for pedagogical purposes only, and the multiple-access communication system may comprise plurality of ATs and APs.

**[1029]** In one embodiment, each AP in the communication system **400** transmits known signal, called a pilot signal. In one embodiment, the pilot signal is transmitted at well-defined, periodic intervals on the forward traffic

channel. In another embodiment, the pilot signal is transmitted continuously on a separate forward channel. For the purposes of this description, channel is a route for transmitting signals distinct from other parallel routes; thus, channel routes may be separated by e.g., a frequency division, a time division, a code division, and others known to one skilled in the art.

**[1030]** **FIG. 5** illustrates an exemplary forward link waveform **500**. For pedagogical reasons, the waveform **500** is modeled after a forward link waveform of the above-mentioned HDR system. However, one of ordinary skill in the art will understand that the teaching is applicable to different waveforms. Thus, for example, in one embodiment, the waveform does not need to contain pilot signal bursts, and the pilot signal can be transmitted on a separate channel, which can be continuous or bursty. The forward link **500** is defined in terms of frames. A frame is a structure comprising 16 time-slots **502**, each time-slot **502** being 2048 chips long, corresponding to a 1.66. ms. time-slot duration, and, consequently, a 26.66. ms. frame duration. For the purposes of this description, a time-slot is a fixed time interval comprising a variable number of bits, depending on a data rate. Each time-slot **502** is divided into two half-time-slots **502a**, **502b**, with pilot bursts **504a**, **504b** transmitted within each half-time-slot **502a**, **502b**. In the exemplary embodiment, each pilot burst **504a**, **504b** is 96 chips long, and is centered at the mid-point of its associated half-time-slot **502a**, **502b**. The pilot bursts **504a**, **504b** comprise a pilot channel signal covered by a Walsh cover with index 0. A forward medium access control channel (MAC) **506** forms two bursts, which are transmitted immediately before and immediately after the pilot burst **504** of each half-time-slot **502**. In the exemplary embodiment, the MAC is composed of up to 64 code channels, which are orthogonally covered by 64-ary Walsh codes. Each code channel is identified by a MAC index, which has a value between 1 and 64, and identifies a unique 64-ary Walsh cover. A reverse power control channel (RPC) is used to regulate the power of the reverse link signals for each subscriber station. The RPC is assigned to one of the available MACs with MAC index between 5 and 63. The MAC with MAC index 4 is used for a reverse activity channel (RA), which performs flow control on the reverse traffic channel. The forward link traffic channel and control channel payload is sent in the remaining portions

**508a** of the first half-time-slot **502a** and the remaining portions **508b** of the second half-time-slot **502b**.

**[1031]** The pilot burst **504** provides the ATs with means for predicting a quality metric of the received signal. Referring back to **FIG. 4**, initially, the AP **402** and one of the ATs, e.g., AT **404**, establish a communication link using a predetermined access procedure. In this connected state, the AT **404** is able to receive data and control messages from the AP **402**, and is able to transmit data and control messages to the AP **402**. The AT **404** then monitors the forward link for transmissions from all the APs in an active set of the AT **404**. The active set comprises list of all the APs capable of communication with the AT **404**. The AT **404** then determines for each AP in the AT **404** active set a quality metric for the forward link, which in one embodiment comprises a signal-to-noise-and-interference ratio (SINR). In one embodiment, the AT **404** monitors the pilot bursts **504** (of **FIG. 5**) received from all the APs belonging to the AT **404** active set, and utilizes the pilot bursts **502** to determine the SINR of the forward link signals. If the quality metric from a particular AP, e.g., AP **402**, is above a predetermined add threshold or below a predetermined drop threshold, the AT **404** reports this to the AP **402**. Subsequent messages from the AP **402** direct the AT **404** to add to or delete from its active set the particular AP. Based on the SINR information over past signal segment(s) from each of the APs in the AT **404** active set, the AT **404** predicts the SINR over future signal segment(s) for each of the APs in the AT **404** active set. In one embodiment, the signal segment is a time slot. An exemplary prediction method is disclosed in co-pending application serial number 09/394,980 entitled "SYSTEM AND METHOD FOR ACCURATELY PREDICTING SIGNAL TO INTERFERENCE AND NOISE RATIO TO IMPROVE COMMUNICATIONS SYSTEM PERFORMANCE," assigned to the assignee of the present invention. Because different destination stations utilize the pilot burst **504**, an AP **402** must not implement pre-coding on the pilot burst **504**.

**[1032]** The AT **404** continues to measure the SINR of the forward link signals from the APs, and selects the serving AP from the active set based on a set of parameters. The set of parameters can comprise the present and previous SINR measurements and the bit-error-rate or packet-error-rate. In one

embodiment, the serving AP is selected based on the largest SINR measurement. The AT **404** then identifies the serving AP and transmits to the selected AP a data request message (hereinafter referred to as the DRC message) on the data request channel (hereinafter referred to as the DRC channel). The DRC message can contain the requested data rate or, alternatively, an indication of the quality of the forward link channel (e.g., the SINR measurement itself, the bit-error-rate, or the packet-error-rate). In one embodiment, the AT **404** can direct the transmission of the DRC message to a specific AP by the use of a Walsh code which uniquely identifies the base station. The DRC message symbols are exclusively OR'ed (XOR) with the unique Walsh code. Since each AP in the active set of the AT **404** is identified by a unique Walsh code, only the selected AP which performs the identical XOR operation as that performed by the AT **404**, with the correct Walsh code, can correctly decode the DRC message.

**[1033]** In an embodiment, the communication system **400** utilizes a time division duplex (TDD). A TDD means that both the forward link and the reverse link are transmitted on the same carrier frequency. Due to the frequency reciprocity, the characteristic of the forward link and the reverse link are equal. Therefore, the AP may use the reverse link impulse response estimate to carry out pre-equalization on the forward link. In one embodiment, the AP **402** estimates the reverse link impulse response from the signals sent by the AT **404** on the reverse link.

**[1034]** In another embodiment, the communication system **400** utilizes a frequency division duplex (FDD). A FDD means that the forward link is carried on one carrier frequency, and the reverse link is carried on a different carrier frequency. Because of the carrier frequency difference, the characteristic of the forward link and the reverse link will generally be different. Therefore, to characterize the forward link in FDD systems, the AT **404** uses the pilot burst **502** to estimate the forward link characteristics A(z). The forward link characteristics comprises an impulse response, a transfer function or other characteristics known to one skilled in the art. The AT **404** then transmits the channel impulse response that it determined to the AP on a reverse link channel.

[1035] When data to be transmitted to the AT **404** arrive to the controller **412**, in one embodiment, the controller **412** sends the data to all APs in AT **404** active set over the backhaul **414**. The term backhaul is used to mean a communication link between a controller and an AP. In another embodiment, the controller **412** first determines which AP was selected by the AT **404** as the serving AP, e.g., AP **402**, and then sends the data to the determined AP. The data are stored in a queue at the AP(s). A paging message is then sent by one or more APs to the AT **404** on the respective control channels. The AT **404** demodulates and decodes the signals on one or more control channels to receive the paging messages.

[1036] At each time slot, the AP **402** can select any of the paged AT for data transmission. The AP **402** uses the rate control information received from each AT in the DRC message to efficiently transmit forward link data at the highest possible rate. In one embodiment, the AP **402** determines the data rate at which to transmit the data to the AT **404** based on the most recent value of the DRC message received from the AT **404**. Additionally, the AP **402** uses the channel characteristic A(z) received over the reverse channel to pre-code the data portion of the forward link with the above-discussed principles.

[1037] The AT **404**, for which the data is intended, receives the data transmission and decodes the data. In one embodiment the AT **404** may use the pilot burst **504** to estimate the complex channel gain of the communication channel and utilize this estimate for demodulation of data. As explained, the pilot signal is used to estimate the forward link characteristic $A(z)$, yielding an estimate $\hat{A}(z)$. A data symbol *t* is then pre-coded by $\frac{1}{\hat{A}(z)}$, and sent over a forward link. The AT **404** receives a signal symbol *r* corresponding to the transmitted symbol *t* given by the following Equation:

$$r = t \cdot \frac{1}{\hat{A}(z)} \cdot A(z) + n \approx t \cdot a \cdot e^{-j\theta} + n \qquad (5)$$

where:

$a$ is an amplitude introduced by difference between $\hat{A}(z)$ and $A(z)$;

$e$ is a base of natural system of logarithms;

$\theta$ is a phase introduced by difference between $\hat{A}(z)$ and $A(z)$; and

$n$ is a noise added by the forward link.

**[1038]** To remove the amplitude and the phase distortion, an estimate of the link complex gain is required. It follows from Equation (5) that if the signal symbol $r$ is known at the AT **404**, the AT **404** can calculate the amplitude $a$ and the phase $\theta$. Although the pilot burst **402** is a known signal, because the pilot burst **402** was not pre-coded, the quality metric on the desired multi-path of the common pilot channel is, due to the presence of an unequalized pilot channel multi-path, smaller than the quality metric of the data channel with equalized multi-paths. Consequently, the link characteristic estimated from the received pilot signal is different from the data link with equalized multi-paths. Therefore, Equation (5) is not satisfied, and the noisy channel characteristic estimate may reduce performance of a receiver (not shown) at the AT **404**. In order to improve the link estimation for data demodulation, in accordance with one embodiment, an additional pilot signal, referred to as a dedicated pilot signal is introduced on the forward link. The dedicated pilot signal is pre-coded in the same manner as the data destined to a specific destination station. Consequently, the dedicated pilot signal is equalized, and the specific destination station uses the dedicated pilot signal for demodulation. In one embodiment, the dedicated pilot signal is transmitted at well-defined, periodic intervals on the forward traffic channel. In another embodiment, the dedicated pilot signal is transmitted continuously on a separate forward channel.

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A4 **[1039]** **FIG. 6** is a simplified illustration of a forward link channel time-slot **600** in accordance with one embodiment of the invention. The time-slot **600** contains a pilot burst **602**, data **604a, 604b, 604c**, and dedicated pilot burst **606**. Because the forward link is comprised of frames, wherein each frame comprises a concatenation of number of time-slots, the pilot burst **602** and the dedicated pilot burst **606** repeat themselves periodically. One of ordinary skills in the art understands that all other channels necessary supporting other functions of the communication system as described in reference to **FIG. 5** are

present in the forward link channel time-slot 600, e.g., MAC, RBC, and other channels. In accordance with this embodiment, the pilot burst **602** provides the destination stations with a means of predicting a quality metric of the received signal. In one embodiment, the quality metric is a carrier-to-interference ratio (C/I). Because different destination stations utilize the pilot burst **602**, an origination station must not implement pre-coding on the pilot burst **602**. The dedicated pilot burst **606** is pre-coded in the same manner as the data destined to a specific AT. The specific AT uses the dedicated pilot burst **606** for demodulation in accordance with the above-described principles.

**[1040]** However, one of ordinary skill in the art will understand that the teaching is applicable to different waveforms. Thus, for example, in one embodiment, the pilot burst and the dedicated pilot burst can be sent in each half time slot. Consequently, a time slot in accordance with this embodiment would comprise two half time-slots, each time-slot having the structure as illustrated in **FIG. 6**. In another embodiment, the waveform contains the dedicated pilot signal bursts, and the pilot signal can be transmitted on separate channel, which can be continuous or bursty.

**[1041]** **FIG. 7** is a block diagram of an AP **700**, in accordance with one embodiment of the invention. Data to be transmitted are provided by a variable data source **702** to a processor **704**. The processor **704** processes the data in accordance with CDMA principles and provides the data to a pre-coder **706**. The pre-coder **706** pre-codes the data and provides the data to a transmitter **708**. The transmitter **708** is further provided with a pilot signal generated by a pilot source **710** and processed in accordance with CDMA principles by a processor **712**. In accordance with one embodiment of the invention, the transmitter **708** multiplexes the pre-coded data and the pilot signal to provide channel time-slots in accordance with principles described with reference to **FIG. 5.**

**[1042]** In accordance with another embodiment of the invention, the origination station **700** further comprises dedicated pilot source **714**. The pilot data provided by the dedicated pilot source **714** is processed in accordance with CDMA principles by processor **716**, and provided to the pre-coder **706**. The pre-coder **706** pre-codes the pilot data and provides the processed pilot

data to the transmitter **708**. The transmitter **708** multiplexes the pre-coded data, the pilot signal, and the dedicated pilot signal to provide channel time-slots in accordance with principles described with reference to **FIG.6.**

**[1043]** The channel time-slots are then quadrature spread, baseband filtered, upconverted and transmitted from antenna **718** on a forward link **406**.

**[1044]** Signals on a reverse link **408** are received by an antenna **720** and provided to a receiver **722**, which downconverts, filters and despreads the signal. The despread signal is provided to a demodulator **724** and further to a processor **726**. The processor **726** extracts a data rate control signal and provides it to the processor **704**.

**[1045]** If a FDD communication system is utilized, the channel impulse response seen by the AT and the AP are generally different. Therefore, in FDD systems the AT must transmit the channel impulse response that it determined to the AP on a reverse link feedback channel. Therefore, the processor **726** further extracts the impulse response information and provides the estimate to the pre-coder **706**.

**[1046]** In a TDD communication system, where both the AT and the AP transmit on same frequency, the AP, due to the reciprocity of the forward and reverse link channels, may use its own channel impulse response estimate to carry out pre-equalization on the forward link. In this embodiment, the processor **726** estimates the channel impulse response from the signals sent on the reverse link and provides the estimate to the pre-coder **706**. The data is provided to data sink **728**.

**[1047]** **FIG. 8** is a block diagram of an AT **800** in accordance with one embodiment of the invention. The signal on the forward link **406** are captured by an antenna **802** and provided to a receiver **804**, which downconverts, filters, and despreads the signal. The signal is provided to a pilot detector **806** and a demodulator **808**. The pilot detector **806** detects and extracts a pilot signal, which is then provided to a processor **810**.

**[1048]** In accordance with one embodiment of the invention, the processor **810** uses the pilot burst to estimate the complex channel gain of the channel that the AT **800** believes has been pre-coded by the AP, and provides this estimate to the demodulator **808.** The demodulator **808** utilizes this estimate for demodulation of the data.

**[1049]** In accordance with another embodiment of the invention, the processor **810** uses the dedicated pilot burst to estimate the complex channel gain of the channel that has been pre-coded by the AP and provides this estimate to the demodulator **808.** The demodulator **808** utilizes this estimate for demodulation of the data.

**[1050]** The processor **810** further uses the pilot burst to estimate the SINR, and uses this value to predict the SINR of the pre-coded signal over at least one next time-slot. The predicted SINR value is then used to generate a DRC, which is provided to a processor **818.** The processor **818** provides the DRC together with the complex channel gain and traffic data to be transmitted, which are generated by data source **816,** to transmitter **820**. The data are then quadrature spread, baseband filtered, upconverted and transmitted from antenna **822** on reverse link **408**.

<u>Extension to Multiple Receiving Antennae</u>

**[1051]** **FIG. 9** illustrates extension of the above-described concept to an often-used configuration of a communication system, where an AP **902** transmit a signal from one antenna **908**, and an AT **916** receives the signal at multiple antennae. For the purposes of explanation, only two antennae **914a** and **914b** are illustrated. One of ordinary skills in the art will understand how to extend the described embodiments to multiple antennae.

**[1052]** The AP **902** comprises a data source **904**, which provides data to a pre-coder **906** that pre-codes the data in accordance with a function G(z) in accordance with the above-described embodiments. One of ordinary skills in the art understands that although not shown in **FIG. 9**, the AP **902** further comprises all the illustrative logical blocks, modules, and circuits as illustrated in

reference to **FIG. 7** and accompanying text, necessary to generate a forward link waveform in accordance with the above-described embodiments. The forward link waveform is then transmitted via an antenna **908**.

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**[1053]** The forward link waveform arrive at an antenna **914a** of the AT **916** over a communication channel **910a**, characterized by a transfer function $C_1(z)$. The communication channel **910a** introduces noise **912a**, and the resulting signal and noise are provided to an equalizer **918a**, characterized by a transfer function $H_1(z)$. The data also arrive at an antenna **914b** of the AT **916** over a communication channel **910b**, characterized by a transfer function $C_2(z)$. The communication channel **910b** introduces noise **912b**, and the resulting signal and noise are provided to an equalizer **918b**, characterized by a transfer function $H_2(z)$. Consequently, the demodulator **922** at the output of the summer **920** receives a signal modified by the transfer function $R(z)$, given by the following equation:

$$R(z) = G(z) \cdot C_1(z) \cdot H_1(z) + G(z) \cdot C_2(z) \cdot H_2(z) \qquad (5)$$

The AT **916** estimates the transfer functions $C_1(z)$, $C_2(z)$, in accordance with the above-described embodiments and adjusts $H_1(z)$, $H_2(z)$, and $G(z)$ to optimize a signal quality metric, e.g., maximum SINR at the demodulator **922**. The data decoded in accordance with the above-described embodiments are provided to a data sink **924**. The destination station **916** then computes and reports $G(z)$ back to the origination station **902**.

**[1054]** One of ordinary skills in the art understands that although not shown in **FIG. 9**, the AT **916** further comprises all the illustrative logical blocks, modules, and circuits as illustrated in reference to **FIG. 8** and accompanying text, necessary to carry out the processing (e.g., forward link reception, pilot signal extraction, channel estimation) in accordance with the above-described embodiments.

[1055] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[1056] Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[1057] Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

[1058] The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete

gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

**[1059]** The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal (presumably previously defined broadly). In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

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